

Chapter 1

Introduction

Past studies have identified urban combined sewer overflow (CSO) and stormwater runoff as major contributors to the degradation of many urban lakes, streams, and rivers. Sewage solids deposited in combined sewer (CS) systems during dry weather are major contributors to the CSO-pollution load. In recent years, pollution caused by CSO has become a serious environmental concern. Although requirements vary from state to state concerning allowable overflow frequencies, compliance has resulted in the design and construction of storage facilities as well as utilization of in-line storage or constructing deep tunnels. In the case of in-line storage, shallow slopes and low mean velocities allow debris to settle along the invert of the pipe during storage periods. Accumulation of sediments results in a loss of storage capacity that may cause surcharge or local flooding and the establishment of septic conditions that create odor and corrosion problems.

Some simple calculations illustrate the potential impacts of overflows on receiving waters. Estimates of dry weather flow deposition in combined sewer systems have ranged from 5 to 30 percent of the daily pollution loading. If 25 percent of the daily pollution loading accumulates in the collection system, an intense rainstorm lasting two hours after four days of antecedent dry weather may wash the equivalent of a one-day's flow of raw wastewater overboard to the receiving waters. The average antecedent dry period between storm events is about four days for many areas of the U.S., especially along the eastern seaboard. Furthermore, a one-day equivalent of raw wastewater discharged within a two-hour period, is twelve times the rate at which raw wastewater enters the collection system.

This report will demonstrate that sewer system and storage tank flushing that reduces sediment deposition and accumulation is of prime importance to optimizing performance, maintaining structural integrity, and minimizing pollution of receiving waters.

Project Scope

The U.S. Environmental Protection Agency's (EPA's) National Risk Management Research Laboratory's (NRMRL's) Office of Research and Development's Urban Watershed Management Branch, Water Supply and Water Resources Division have supported the development of this project report for the investigation of sewer and tank sediment flushing. The report is designed to provide information and guidance to meet the following objectives:

1. Investigate the cost-effectiveness of combined sewer in-line and CSO storage tank flushing systems for removing combined sewer sediments and CSO storage tank bottom deposits at actual installation sites in urban watersheds.
2. Develop a long-term combined sewer hydrogen sulfide monitoring program.

To meet these objectives, the following tasks were developed:

1. Identification of 18 sites in North America and Europe for evaluation of in-line (10) and CSO storage tank (8) flushing systems.
2. Desk Top analyses of published and unpublished information on the range of hydrogen sulfide concentration combined sewers, the correlation between sediment characteristics and hydrogen sulfide generation, and the effectiveness of combined sewer flushing systems to:
 - Decrease the rate of hydrogen sulfide generation during dry weather conditions by removing an important and often significant contributory source of available microbial food;

- Eliminate potential for creating highly unsafe transitory hydrogen sulfide levels associated with rapid biological activity of resuspended sediments during high flow conditions;
 - Lessen the potential for sewer decomposition associated with elevated hydrogen sulfide generation; and
 - Maximize sewer flow carrying capacity by removing sediment/blockages.
3. Collect and analyze operational information on the 18 identified sites regarding:
 - The effectiveness of systems design in terms of sediment removal;
 - Capital and operation and maintenance costs;
 - Operational problems and lessons learned from these sites.
 4. Perform cost-effective-benefit analyses of the 18 identified/selected in-line and storage tank flushing systems.
 5. Develop a generic Quality Assurance Protection Plan (QAPP) for conducting a field program for monitoring and analyzing long term sediment characteristics and hydrogen sulfide generation rates within a problem combined sewer system.

Background

Innovative methods for cleaning accumulated sludge and debris in CSO and stormwater conveyance systems and storage tanks have emerged over the last 15 years by creating high speed flushing waves to resuspend deposited sediments. In the last ten years, at least three new passive hydraulic systems have been developed and installed in Europe to routinely flush sewer deposits and wet weather storage tanks. In Europe, 77 installations have been in operation since 1985 to flush sewers, interceptors and tunnels ranging from 0.25 to 4.3 meters (10 inches to 14 feet) in diameter and flushing lengths of up to 335 meters (1100 feet) for large diameter pipes and 1000 meters (3300 feet) for smaller diameter.

Cleansing efficiency of periodic flush waves depends on flush volume, flush discharge rate, sewer slope, sewer length, sewer flow rate, sewer diameter and population density. Maximum flushing volumes at upstream points are limited by available space, hydraulic limitations and costs. Maximum flushing rates at the downstream point are limited by the regulator/interceptor capacities prior to overflow. The relationship between cleaning efficiency and pipe length is important. The aim of flushing is to wash the resuspended sediment to strategic locations, i.e., to a point where the waste stream is flowing with sufficient velocity, to another point where flushing will be initiated, to a storage sump which will allow later removal of the stored contents, or to the wastewater treatment plant (WWTP). This reduces the amount of solids resuspended during storm events, lessens the need for CSO treatment and sludge removal at downstream storage facilities, and allows the conveyance of more flow to the WWTP or to the drainage outlet.

Flushing gates and tipping flushers for cleaning accumulated sludge and debris in CSO and stormwater storage tanks have emerged in Germany and Switzerland. Both methods create high speed flushing waves to resuspend sediments on the tank floor and sweep these materials to a disposal channel at the end of the tank. The flushing gate system has been used extensively in Europe with 209 installations and 436 units in operation since 1985. Approximately 60 percent of the installations are for cleaning sediments from CSO tanks. The tipping flushers were initially developed in Switzerland, and were optimized to present design in Germany. Presently there are several thousand CSO tanks throughout Europe using the tipping gate technology.

Odor and Corrosion Perspective

Sewer sediments create odor and sewer decomposition problems in addition to CSO pollution. The production and release of hydrogen sulfide gas in municipal wastewater collection systems is responsible for numerous odor complaints and the destruction of sewer pipes and other wastewater facilities. Sulfates are released from organic substances contained in the sewer sediments by bacteria under anaerobic conditions. In the absence of dissolved oxygen and nitrates, sulfates serve as electron acceptors and are chemically reduced to sulfides and to hydrogen sulfide by bacteria. The hydrogen sulfide is then converted to sulfuric acid, which disintegrates the sewer pipes.

The process begins with the biological reduction of sulfate to sulfide by the anaerobic slime layer residing below the water surface in wastewater collection systems. The anaerobic bacteria utilize the oxygen in the sulfate ion as an electron acceptor in their metabolic processes. The resulting sulfide ion is transformed into hydrogen sulfide gas after picking up two hydrogen ions from wastewater.

Once released to the sewer atmosphere, aerobic bacteria (*Thiobacillus*) which reside on sewer walls and surfaces above the water line consume the hydrogen sulfide gas and secrete sulfuric acid. In severe instances, the pH of the pipe can reach 0.5. This causes severe damage to unprotected collection system surfaces and may eventually result in the total failure of the sewer piping and the uncontrolled release of raw wastewater to the environment.

For obvious reason, the control and reduction of hydrogen sulfide in wastewater systems is of vital importance. While, the biological and chemical processes resulting in sulfide production in wastewater are well understood, there are significant contributing factors are not understood. Even the well known Pomeroy-Parkhurst equations contains an empirical "M Factor" to account for the unknown biological and chemical transformations which occur with sulfide in wastewater (USEPA, 1985).

Settled solids and other debris in sanitary sewers and wastewater collection systems can provide a greatly increased surface area upon which anaerobic sulfate reducing bacterial slime can grow, thereby increasing the incremental (per foot) sulfide production potential of sewers. Methods need to be developed to measure the sulfide production in a sewer with moderate to heavy settled solids and debris and sample and to characterize the solids in the sewer.

It is important to develop a method to measure in-situ dissolved sulfide concentrations inside the interstitial spaces of a typical debris pile in the sewer. By measuring the pore space dissolved sulfide concentration in a typical debris pile and by removing the debris pile and characterizing the debris by sieve size and mineralogy, the additional surface area provided by the pile can be calculated. From knowledge of the practical pore space volume and the surface area, the specific sulfide production rate can be determined. This would allow calculation of the mass of sulfide that could be prevented by cleaning the upstream sewers.

The method analyzed to clean the pipes in this study is passive flushing. This technology holds great potential as an economical way to maintain sewers in a clean and free flowing condition. Clean sewers provide maximum wastewater carrying capacity thereby preventing sewer overflows and protecting the environment. There is another benefit to be gained by maintaining sewers in a clean and free flowing condition, namely, sulfide odor and corrosion reduction. However, the flushing event that disturbs the settled debris and solids and carries them downstream will generate a significant turbulent wave. This hydraulic wave will release the sulfide in the debris pore spaces and subject it to turbulence. The turbulence associated with the hydraulic wave will strip dissolved sulfide from the wastewater and release it as hydrogen sulfide gas. Although the event is short-lived, the concentrations produced may cause a short burst of odor release from the sewer that could result in odor complaints. Identification of the potential for odor release and complaints as a result of sewer flushing may require measurement of the instantaneous spike in sewer headspace hydrogen sulfide concentrations caused by the hydraulic wave. Sewers that

have not been cleaned in many years may have accumulated significant debris piles that may cause a large spike in hydrogen sulfide release when first flushed. However, following one or two flush events, the debris piles should be smaller or totally removed, thus reducing the hydrogen sulfide spikes for the second, third and subsequent flushing events.

Previous Research

In 1966, EPA through its federal water program initiated research to demonstrate the feasibility of periodic flushing during dry weather. The first phase of work performed by FMC Corporation included a study of the overall flushing concept, small-scale hydraulic modeling, and design and development of cost estimates for constructing test equipment (FMC, 1966). The second phase produced a flushing evaluation facility consisting of 0.30 meter and 0.45 meter (12 and 18 inch) diameter test sewers about 488 meters (1600) feet long, supported above ground (thus allowing for slope adjustment), including holding tanks at three points along the test sewer for the flushing experiments (FMC, 1972). Limited periodic flushing of simulated combined sewer laterals was accomplished. The report documenting this research recommended a third phase be made for flushing larger sizes of pipe, flush wave sequencing, and determination of solids buildup over long periods of time.

In 1974, a combined sewer management study performed by Process Research, Inc., Cambridge, Massachusetts, focused on assessing alternative strategies for abating CSO discharges to portions of Boston Harbor was completed (Process Research, 1974). As part of the research work conducted during this study a number of theoretical formulas for prediction of dry weather deposition and flushing criteria were developed. The development of the deposition analysis techniques stemmed from critical fluid shear stress considerations. The theoretical formulas were roughly field checked to ascertain solids accumulations. Although the model was crude, the agreement with visual field observations was reasonable. The model was then used to analyze deposition problem segments within a service area of 1200 hectares (3000 acres) entailing roughly 152,500 meters (0.5 million feet) of sewer. Roughly 3000 manhole-to-manhole segments were analyzed for deposition and it was determined that roughly 17 percent of the segments contained about 75 percent of the estimated dry weather wastewater depositions. It turned out that most of these segments were small-diameter combined sewer laterals. Flushing criteria were empirically developed using data generated during the earlier FMC research to estimate required flushing volumes.

In 1979, a three year research and development (R&D) program sponsored by EPA was conducted by Environmental Design & Planning, Inc. (EDP) in the Dorchester area of Boston to determine the pollution reduction potential of flushing combined sewer laterals. It was concluded that small volume flushing would transport organics/nutrients and heavy metals sufficient distances to make the option feasible and attractive (EPA, 1979). Relevant conclusions were as follows:

- Approximately 20 to 40 percent of heavy metal (cadmium, chromium, copper, lead, nickel, and zinc) associated with particles entrained by flush waves will not settle within a two hour settling period.
- An automated sewer flushing module using a simple hydraulic gate powered by an air cylinder, and time clock triggered, operated without intervention for a 5.5-month period to back up wastewater and retract and induce flush waves. Flushed pollutant loads were comparable to removals noted by manual flush tanker means.
- An empirical methodology was prepared for providing first-cut deposition solids, nutrient and organic daily collection system estimates simply by knowing the total length of pipe, service area, average pipe slope or ground slope, and per capita wastewater flow rate. Methods were also developed to determine which segments in collection systems should be flushed to remove specified portions of deposits.

Based on the prototype success of the flushing R&D project, a full-scale demonstration project was recommended to obtain full-scale experience in Boston. Clinton Bogert & Associates completed a detailed cost-effectiveness study in 1980 with support from EDP focusing on the Dorchester neighborhood in Boston. It was concluded from the cost-effectiveness analysis that sewer flushing can be an adjunct to, but cannot substitute for, structural alternatives and that the use of storage treatment available in large combined sewers in conjunction with sewer flushing could reduce the cost of large stand-alone satellite storage facilities.

Sewer flushing of large-diameter combined sewers was investigated in the CSO Facility Plan for the City of Elizabeth, NJ by Clinton Bogert & Associates. It was concluded that daily flushing of troublesome deposition section within seven sub-areas using 12 automatic flushing systems was estimated to reduce about 28 percent of the first flush overflow pollutant loading from the service area. Control is by level sensing to centralized computer control. Combined sewers to be flushed ranged from 0.45 to 1.4 meters (18 to 54 inches). Construction of 12 flushing modules was completed in 1990. Estimated construction costs for complete modules (structural, mechanical, electrical, and site work excluding computer control) ranged from \$175,000 for small diameter lines up to \$275,000 (costs based on ENR cost index of 5000). No evaluation data has been reported regarding effectiveness.